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Effect of filler nature and content on the bituminous mastic behaviour under cyclic loads

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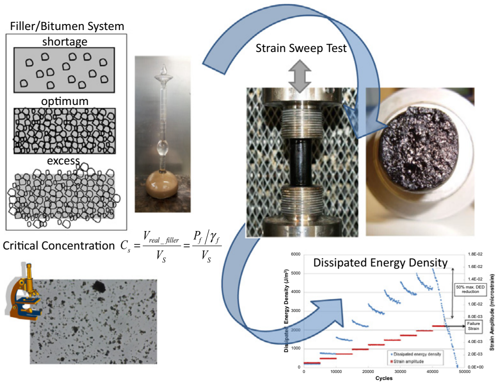
HIGHLIGHTS

- Mastic design by volume should be considered instead of typical design by weight.
- Mastic stiffness and failure strain were evaluated using a strain sweep test.
- The behaviour of hydrated lime is different from that of natural fillers.
- Granite stiffens the mastic excessively, especially at low temperatures.
- Limestone filler has the best fatigue behaviour.

GRAPHICAL ABSTRACT



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ABSTRACT

The role of the filler in asphalt mixtures is particularly important because of its influence on mastic behaviour. The filler improves the resistance properties of bitumen against the action of traffic loads and temperature. However, the filler can also adversely affect bitumen in mastics excessively brittle and stiff due to inappropriate design. For these reasons, it is interesting to investigate the effect of filler type and content on mastic composition. This paper presents results from a strain sweep test applied to bituminous mastics prepared with different filler types and contents at several temperatures. The obtained stiffness modulus and failure strain results provide information to assess the fatigue behaviour of the analysed mastics.

1. Introduction

Bituminous mastic obtained by mixing a filler with a bituminous binder greatly affects the behaviour of the bituminous mixture. It is known that the addition of filler increases the viscosity, stiffness and tensile strength of bitumen, leading to improved mixture cohesion and reduced thermal susceptibility [1].

The most extensively studied physico-chemical variables of fillers related to mastic behaviour are shape, size, nature and content [2–7]. Regarding the degree of packing of filler particles, significant differences exist between natural fillers. Moreover, the degree of packing has been found to affect both mastic and mixture behaviour, although no correlation has been observed between test

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results of mastics and mixtures due to complex interactions between the components of the mixture [8].

Some researchers have designed equipment to study the effect of filler particle size on the viscoelastic properties of mastic. For example, Delaporte et al. [9,10] developed an annular shear rheometer and concluded that the use of ultrafine particles increases the complex modulus of mastic at high temperature, compared to mastic prepared with conventional fillers.

Clopotel et al. proposed a novel method to estimate the change in viscosity of binders due to the addition of fillers using glass transition temperature measurements [11]. Hesami et al. [12,13] developed an empirical framework for determining mastic viscosity as a function of filler concentration, demonstrating once again the complexity of studying the behaviour of bituminous mastics.

It is equally important to highlight the adverse effects of high filler contents in mastic, such as decrease in ductility, as too much filler can lead to fragile and brittle mastic. Furthermore, the filler can sometimes have a hydrophilic character, i.e. a greater ability to combine with water than with bituminous binder. This can result in a stripping process of the mixture in the presence of water, resulting in loss of cohesion and strength.

Therefore, the composition of the mastic should be carefully studied to select the appropriate filler type and content to be incorporated in order to achieve the desired physico-mechanical and volumetric properties. Former investigations by Rigden [14] and Ruiz [15,16] propose to limit filler addition to avoid an excessive volumetric concentration in the filler-bitumen system; this “over fillerization” would lead to high stiffness and the resulting loss of resistance to deformation, especially at low temperatures.

Buttlar et al. [17] conducted an experimental program to predict the properties of mastic in a wide range of temperatures and with different filler contents. They found that particle-interaction reinforcement may play a minor role at low filler concentrations whereas this mechanism is significant at high filler contents. They also concluded that hydrated lime provided a much higher level of physicochemical reinforcement than baghouse fillers.

A recent study on Test Methods and Specification Criteria for Mineral Filler Used in HMA [18] conducted at the University of Wisconsin-Madison developed and set some models to define indicators of workability, resistance to plastic deformation and stiffness at low temperatures. Faheem et al. proposed a model for predicting the complex modulus of the mastic as a function of the filler and bitumen properties [19]. Shen et al. [20] verified the application of the Ratio of Dissipated Energy Change (RDEC) approach to evaluate the fatigue properties of viscoelastic materials, (bituminous mixtures, mastics and binders), and found a unique relationship between the parameter determined with this RDEC concept and the corresponding fatigue life, independent of the material type and loading mode. Yin et al. [21] carried out a research to assess the micromechanical models developed to predict complex modulus and analyse the simplifications and limitations assumed in each model. They found that the simplifications of some models affected the accuracy of the predictions, underestimating some of the mastic properties or overestimating the experimental results.

The present study aims to analyse the effect of filler type and content on the fatigue behaviour of mastics at different temperatures by a strain sweep test (EBADE test, in Spanish *Ensayo de BArrido de DEformaciones*, which stands for “strain sweep test”) [22], developed at the Road Research Laboratory of the Universitat Politècnica de Catalunya.

2. Materials

Three different mastics were prepared with 50/70 penetration grade bitumen and three types of fillers: two natural types, a granite filler and a limestone filler, and a hydrated lime filler. The mineralogical composition of the filler is the cause of the mechanical bonding achieved by the filler-bitumen system, in addition to increasing the viscosity of the bituminous mastic [23].

Mineral dust was added in volumetric concentrations. To this aim, the maximum volume of filler which can be added to thicken the binder film was determined by a sedimentation test to ensure that the binder film coats every filler particle. A viscous hydrocarbon fluid with lower viscosity than bitumen, such as kerosene, can be used to facilitate settlement.

The critical concentration determined by the sedimentation test corresponds to a dispersion of filler particles in the bitumen moving as freely as possible but in contact with each other, that is, when applied stresses in the viscous deformation of the continuous filler-bitumen medium are such that frictional resistance between particles is at a minimum.

Such a particle arrangement is expected in the sediment obtained by simple settling of filler dispersion in a fluid medium chemically related to bitumens, like kerosene. Ruiz [16] proposes a simple sedimentation test to find the critical value which guarantees mastic viscous behaviour. This test is known as “Sediment concentration”, or most commonly, “Critical concentration” [24]. Bressi et al. used an equation to determine critical filler concentration based on Rigden voids and methylene blue value [25].

In this study, critical concentration is calculated with the following equation:

$$C_s = \frac{V_{filler}}{V_s} = \frac{P_f/\gamma_f}{V_s} \tag{1}$$

where C_s critical concentration of filler; V_{filler} volume of filler (cm^3); P_f mass of filler (g); V_s settled volume of filler in anhydrous kerosene after 24 h (cm^3); γ_f density of filler (g/cm^3).

When filler is added to mixtures, bituminous mastic viscosity increases gradually with increasing the volumetric concentration (Cv). In the case of asphalt bitumens, when $Cv > Cs$, the biphasic system stops being viscous and an internal structure determining a net non-Newtonian flow appears, which renders the mix stiff.

Different volumetric concentrations divided by the critical concentration (Cv/Cs) were used for each filler, with Cv being determined by the following equation:

$$C_V = \frac{V_{filler}}{V_{filler} + V_{bitumen}} = \frac{P_f/\gamma_f}{P_f/\gamma_f + P_b/\gamma_b} \tag{2}$$

where C_v volumetric concentration of filler; V_{filler} and $V_{bitumen}$: volume of filler and volume of bitumen (cm^3), respectively; P_f and P_b: mass of filler and mass of bitumen (g), respectively; γ_f and γ_b: density of filler and of bitumen (g/cm^3), respectively.

The Cv/Cs concentrations used in this study are 0 (neat bitumen), 0.5, 1.0 and 1.25. Table 1 shows the characteristics of the bitumens and Table 2 shows the density of the fillers, as well as the critical concentration, and the volumetric and mass concentrations.

Table 1
Characteristics of bitumens. Source: REPSOL.

Characteristics	Unit	Standard	B50/70
Original Bitumen			
Penetration at 25 °C	(0.1 mm)	EN 1426	59
Softening point R&B	(°C)	EN 1427	50.2
Fraass brittle point	(°C)	EN 12593	−11
After RTFOT			
Mass Loss	(%)	EN 12607-1	0.02
Retained penetration at 25 °C	(%)	EN 1426	62
Increase in softening point R&B	(°C)	EN 1427	7.0